Spectrum and Propagation Measurements

The radio spectrum is a natural resource that offers immense benefit to industry, private citizens, and government by supporting a wide range of radio and wireless applications for communications and sensing. Unlike many other natural resources, the spectrum is non-depleting so it can be used indefinitely. However, the rapidly increasing number of radio devices and active competition for improved access to the radio spectrum suggests that its effective use will require increasingly more complex knowledge of the existing signals environment, as well as an understanding of the technical and operational factors that can cause interference between systems that share the spectrum.

NTIA manages the Federal Government's use of the spectrum to ensure maximum benefit to all users while accommodating additional users and new services. Efficient and effective use of the spectrum is a key element in both the NTIA and the ITS missions.

The Spectrum and Propagation Measurements Division of ITS performs measurements and analysis of radio signals to support research and engineering enabling more efficient and effective use of the spectrum. In addition to a well-equipped research laboratory, major tools include the Radio Spectrum Measurement System (RSMS), a van full of very capable computer-controlled radio measurement devices, and the Table Mountain Field Site and Radio Quiet Zone.

The following areas of emphasis are indicative of the work done recently in this Division to support NTIA, other Federal agencies, and industry.

Areas of Emphasis

Radio Spectrum Measurement System (RSMS) Operations
The Institute uses the RSMS to perform measurements of emission characteristics of new or proposed systems, of spectrum occupancy to determine the level of crowding, of EMC characteristics, and to resolve interference problems. The project is funded by NTIA.

RSMS-4 Development
The Institute is developing the next generation measurement hardware and software capabilities to provide RSMS-4 systems with greatly improved measurement and digital signal processing capabilities. System software will provide very flexible control, remote monitoring, uniform data recording and storage, and powerful analysis and display routines. The project is funded by NTIA.

Table Mountain Research
The Institute uses the facilities at an 1800-acre radio quiet zone to perform a wide range of critical spectrum measurements and research. This year such research has included methods for measuring and analyzing background noise, new antenna development, and detailed radar measurements. The project is funded by NTIA.

Spectrum Efficiency Research
The Institute investigates ways that Federal agencies can make more efficient and effective use of the spectrum to accomplish their respective missions. Recent work includes evaluating the use of the 162-174 MHz band by Federal agencies in the Washington, DC, area to assess the hypothetical merits of moving separate Federal mobile radio systems onto various common shared radio systems. This work is funded by NTIA.

Signals, Emission, and Performance Measurements
The Institute studies the signals generated by both existing and proposed new communication systems, develops methods for characterizing these signals, and evaluates the effects that certain signals may have on specific victim receivers. Projects this year have included the development of performance metrics and measurements for the NOAA Weather Radio system, and investigation into the effects of various ultrawideband (UWB) signals on wideband receivers. This work is funded through reimbursable agreements with other government agencies, and cooperative research and development agreements (CRADAs) with private industry.

Radio Spectrum Measurement System (RSMS) Operations

Outputs

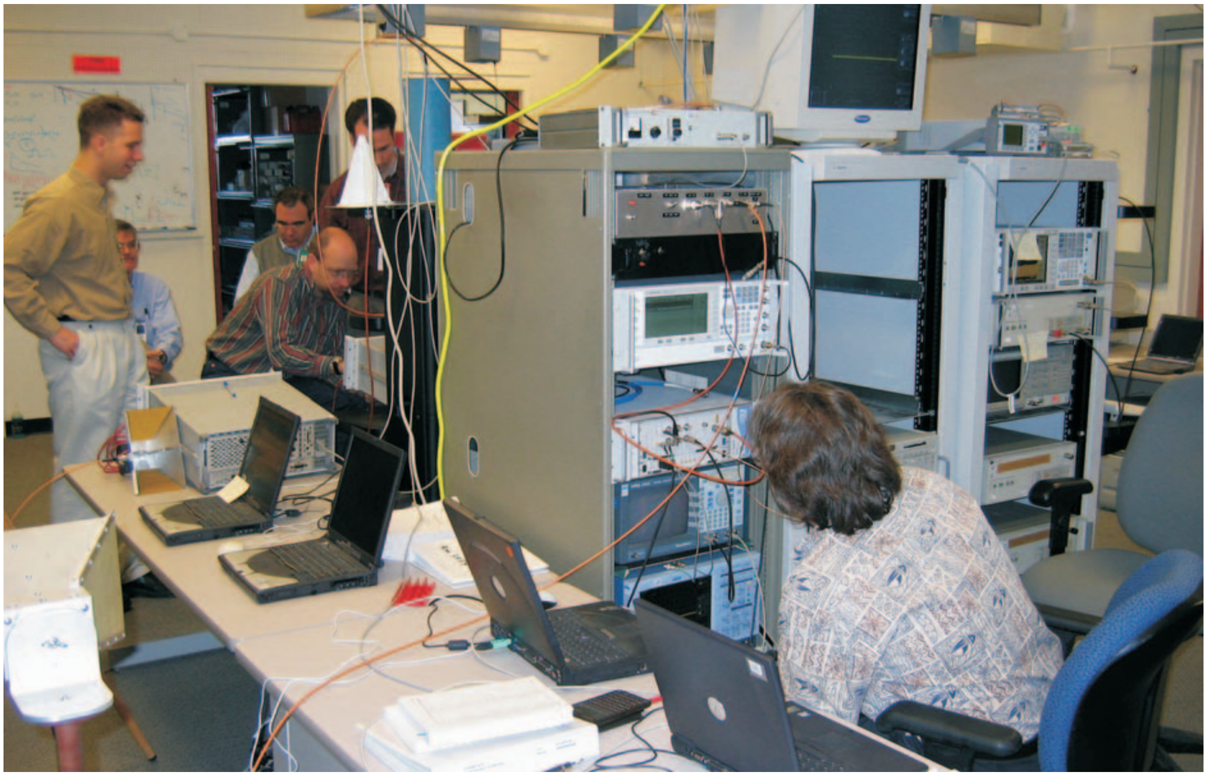
- Measurements to determine radio emission levels from broadband over power lines.
- Measurements to determine move-times and detection thresholds of dynamic frequency selection (DFS) devices.
- Measurements to determine the nature and extent of interference disrupting operations of an Air Force S-band satellite earth station receiver downlink.
- Measurements to determine radionavigation satellite service (RNSS) compatibility with radiolocation services in the 1260-1300 MHz band.

The Radio Spectrum Measurement System (RSMS) is a collection of equipment, measurement routines, and qualified personnel for performing critically needed radio signal measurements necessary for making decisions regarding Federal Government spectrum allocations. As stated under Departmental Organization Order 25-7, issued 5 October 1992, and amended 3 December 1993, the NTIA Office of Spectrum Management (OSM) is responsible for identifying and making arrangements for measurements necessary to provide NTIA and the various departments and agencies with information to ensure effective and efficient use of the spectrum. The RSMS resides at ITS in Boulder, and is tasked to perform measurements in support of OSM as required to fulfill their mission. ITS, through the RSMS Operations project, provides OSM and the executive branch with critically needed radio spectrum data, data analysis, reports, and summaries. Four basic areas of RSMS measurement are 1) spectrum surveys and channel usage, 2) equipment characteristics and compliance, 3) interference resolution and compatibility and 4) signal coverage and quality. In FY 2004, several different measurements were performed throughout the year in support of the basic mission.

In October of 2003, ITS personnel performed, as part of an ongoing effort, measurements to determine the radio emission levels from broadband over power lines (BPL). BPL is a new technology that transforms power lines into network cables that can deliver broadband content. BPL is transmitted over an unshielded medium, so the RSMS was used to perform measurements to determine the nature and extent of radiating fields due to this new technology. Three field measurements, each lasting approximately 2 weeks, were first conducted in late FY 2003 and then again in the early part of FY 2004. In conjunction with that work, modeling of the power lines was performed to describe the skyward radiation and the radiation that a mobile receiver would experience. The modeling was used to make predictions that were not easily accomplished by measurements alone. The measurement results and modeling were summarized and provided to OSM, the content of which were included in NTIA Report 04-413 (see Recent Publications below) as a response to an FCC notice of proposed rule making.

In January and April of 2004, laboratory measurements were conducted to determine move-times and detection thresholds of dynamic frequency selection (DFS) devices. DFS is a method whereby radio local area network (RLAN) devices, using the 5 GHz band for unlicensed operations, will detect the operations of radar and promptly evacuate the channel if the radar is present. Measurements were conducted to determine if current DFS devices comply with specifications given in ITU-R M.1658. This testing was used to support NTIA's comments and reply comments to the FCC UNII rule-making (FCC Docket 03-122). ITS support consisted of developing a radar signal simulator, developing testing algorithms, and performing the measurements.

In March of 2004, additional measurements were performed on various ultrawideband (UWB) modulations to validate existing bandwidth correction factor (BWCF) models. UWB is the term applied to very narrowly pulsed signals in which spectral emissions have an instantaneous bandwidth of at least 25% of the center frequency. For those who make policies regarding UWB emissions, it is worthwhile to know, when a certain signal with certain spectral characteristics is measured in one bandwidth, what the power is at another bandwidth. Different pulse spacing modulations of UWB signals result in different spectral characteristics. Focusing on the regions



Dynamic frequency selection compliance measurements performed at ITS (photo by J.R. Hoffman).

where the measurement bandwidth is equal to ½ the pulse repetition frequency (PRF) of the UWB signal, the purpose of the BWCF measurements was to examine the relationship between bandwidth and mean power for several representative UWB modulations. The results were used in compatibility analyses of UWB transmission systems and Federal radiocommunication systems.

In April 2004, ITS was called on to determine the nature and extent of interference that was disrupting operations of an Air Force S-band satellite earth station receiver downlink. Based upon preliminary tests performed at the facility by the Air Force, a correlation had been observed between the interference noted in the satellite receiver and the presence of an apparent spurious emission from the video carrier of a local television station. Measurements using the RSMS were conducted over the course of a week to determine the source of the interference. Results were provided to the Air Force summarizing the source of interference.

In June 2004, measurements were conducted to determine radionavigation satellite service (RNSS) compatibility with radiolocation services in the 1260-1300 MHz band. This work was in support of OSM, as well as the U.S. Administration in ITU-R Working Party 8B. The measurements determined and documented the jamming effects on this type of radar when (and if) the satellite signals in question are ever activated. The tests, which were done in coordination with the FAA, included jamming of actual aircraft blips as traffic was being tracked.

Measurements to determine Land Mobile Radio adjacent channel rejection characteristics were conducted for several months starting May 2004. These measurements are in support of an ongoing project to upgrade the sharing procedures described in Annex I of the NTIA manual.

Recent Publication

B. Bedford, A. Paul, and J. Richards, “Potential interference from broadband over power line (BPL) systems to Federal Government radiocommunications at 1.7 – 80 MHz: Phase 1 Study,”NTIA Report 04-413, Apr. 2004.

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RSMS-4 Development

Outputs

- Functional data acquisition and system control software.
- Integrated measurement system — including spectrum analyzers, digital oscilloscopes, vector signal analyzers, and signal detection devices.
- Fully operational RSMS 4th generation measurement vehicle.

The 4th generation Radio Spectrum Measurement System (RSMS-4) consists of state-of-the-art tools for making measurements to characterize spectrum occupancy, ensure equipment compliance, determine electromagnetic compatibility, and analyze interference problems. The development of RSMS-4 originated out of the need to upgrade to the latest technology used in RSMS operations. RSMS operations directly supports NTIA by providing critical measurement support for determining policies affecting both the public and private sectors. The following new capabilities have been added to the system.

SOFTWARE: The RSMS-4G software has an open-ended architecture that allows nearly unlimited expansion and flexible system configurations. Integral to this flexible architecture are instrument and measurement dynamic link libraries (DLLs).

DLLs have been developed on several key pieces of measurement equipment (including several spectrum analyzers, oscilloscopes, VSAs, modulation domain analyzers, and preselectors). These DLLs contain carefully defined command/query modules that interpret commands common to the different equipment categories. Also included is a Virtual Panel that provides a user friendly graphical interface for manually controlling the device from the computer. So as to standardize their use, each DLL, in turn, has a general instrument interface common to all measurement devices. These DLLs, when completed, provide access for rapid development of automated measurements.

DLLs have also been developed for several different automated measurement procedures. These “Measurement” DLLs also have a user friendly graphical interface for setting up and monitoring the progress of a measurement. Common to all “Measurement” DLLs is a carefully defined interface so that their use can be standardized. Three of these measurement routines were used extensively during the broadband-over-power-line measurements — a calibration procedure, a stepped frequency measurement, and an amplitude probability distribution (APD) measurement. A newly designed Land Mobile Radio (LMR) channel occupancy measurement was utilized during measurements in Washington, DC, this fall (see photo). In addition, a stepped frequency APD measurement has been developed, and an automated swept frequency measurement is in the works.

Features added to the software in FY 2004 include the system configuration module and the preselector manager. The system configuration module provides the user with an easy-to-use graphical interface for designating the configuration and making the control connections to the various instruments in the measurement system. Included is a device database where instrument and discrete device specifications are stored. The preselector manager integrates any and all preselectors in the system so that the measurements simply need to designate a frequency without knowledge of path characteristics.

HARDWARE: Several new pieces of equipment, all of which provide improvements and/or new capabilities, have been added to the already extensive inventory of measurement tools.

- Four spectrum analyzers with powerful digital signal processing capabilities that provide features never before possible in older models.
- Two vector signal analyzers (VSAs) that allow digitization with a bandwidth of 36 MHz, and a instantaneous dynamic range of 90 dB. Included is a suite of software capabilities that allow complex signal analysis and demodulation.
- Two VXI-based signal intercept and collection systems that allow digital acquisition when signals meet specified characteristics and can be used to trigger digitization and analysis by the VSAs. Also included are high speed digital signal processing chips that can be programmed using open-architecture software.
- Two quad input digital oscilloscopes with a front-end bandwidth of 500 MHz and maximum sampling rate of 4 GS/s. Also included are

Radio Spectrum Measurement System (RSMS) 4th generation vehicle performing Land Mobile Radio channel occupancy measurements in the Washington DC area. (photograph by B.L. Bedford).

special smart-triggering capabilities and segmented memory. The latter makes for efficient acquisition of pulsed signals with small duty cycles.

- One wide-bandwidth digital oscilloscope with a front-end bandwidth of 1 GHz and maximum sampling rate of 5 GS/s. This device has specialized peak and sample detection capabilities making it suitable for wide bandwidth acquisition and analysis — including pulsed signals.
- Three new custom-built preselectors that filter and amplify the desired signals. A new flexible configuration preselector was used extensively in recent land mobile radio channel occupancy measurements.

VEHICLE: The following added features in the new measurement vehicle make it possible to perform measurements efficiently and effectively.

- The enclosure has 60 dB effective shielding from all points, making this vehicle particularly suited for measurements in strong signal environments, as well as for noise measurements.
- Internet connections and routers are located throughout the enclosure. There are fiberoptic control lines, multiple power outlets, overhead cable racks, and 3 full instrument racks.
- There are both internet and shore power connections on the outside of the enclosure.
- Racks can be moved forward for rear access, locked into place, or removed entirely.
- There is plenty of counter space, storage space, and head room.
- The enclosure has three 10-meter masts — two in the rear and one in the front.
- There is easy enclosure entry, including retractable staircase with handrails.
- Extra brackets on the roof make it easy to mount antennas.
- The enclosure is powered by a 20 kWatt diesel generator capable of handling demands. for power from full equipment racks — plus air conditioning, and lighting.
- Both air conditioning and heating allow for enclosure temperature control in extreme weather conditions.
- The vehicle is powerful, easy-to-handle, and has sleeping space in the cab.

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Table Mountain Research

Outputs

- Comparison of measured automotive antenna patterns with computer simulations.
- Development of "ITS Interference Test Bed," used to generate and analyze complex signals.
- Development of a 3-axis antenna to study the total incident field and polarization of a signal.
- Radar testing for the ITU-R.
- Cooperative research and development agreements with several private companies for work at the Table Mountain Field Site.

The Table Mountain Field Site and Radio Quiet Zone (see p. 67) supports fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services. To achieve this goal, the Table Mountain Research project actively solicits research proposals from both inside the Institute as well as from external agencies. This research serves to expand the knowledge base available to the Institute, helps identify emerging technologies, and provides for the development of new measurement methods needed to study the characteristics of new devices and systems based on this technology. The results of the Table Mountain work are disseminated to the public via reports, technical papers, journal articles, conference papers, web documents, and computer programs. Highlights of the technical program are presented below.

Comparison of Measured Automotive Antenna Patterns with Computer Simulations

An antenna on a vehicle in a roadway environment does not behave as if it were in free space or over a perfectly conducting ground plane. The gain of the antenna is a function of the antenna geometry, materials used, antenna height above ground, ground conductivity, ground dielectric constant, frequency, elevation angle, and azimuth angle. The performance of an antenna near or on the surface of the earth is also very dependent on the interaction with the lossy earth and the automotive vehicle. Since antennas are commonly mounted on automobiles, an understanding of their performance in this environment is important for police, public safety, military, and commercial applications. This study was undertaken to provide a comparison between real-world measurements of antennas mounted on vehicles and computer simulations of these antennas.

Figure 1. Automotive antenna pattern study at the Table Mountain field site (photograph by J.D. Ewan).

For this study, antenna patterns and gains were measured at the Table Mountain Turntable Antenna Range at multiple frequencies from 41 to 918 MHz. Azimuth antenna patterns at several low elevation angles were measured using the azimuthal rotation of the turntable at multiple receiver antenna heights using a receiver antenna on a tower at a distance from the turntable. Simulation of these measurement scenarios will be completed in FY 2005 and the results will be compared.

The "ITS Interference Test Bed"

ITS is often called upon to evaluate the likelihood that a signal will interfere with a victim receiver. However, testing the effects of planned or proposed signals is complicated, since the transmitters for generating these signals may not yet exist or may only exist as prototype systems with limited availability or functionality. To work around this problem, ITS has developed a new "Interference Test Bed" that can be used to simulate any existing or planned signal without the development of specialized, one of a kind, signal generating hardware. This system also includes new digital analysis equipment that expands measurement and analysis beyond the capabilities of the traditional spectrum analyzer.

Development of a 3-Axis Antenna

Radio receiving antennas are designed to provide their maximum response to signals having specific polarizations and directions of arrival. These features are useful when designing communication systems that require reception of wanted signals and rejection of unwanted, interfering signals. In this case, we usually have some knowledge about the signal we want to detect. However, when performing spectrum surveys we often have little prior knowledge about existing signals, and are more interested in discovering what signals exist. For this case, we desire an antenna that is sensitive to signals incident from any direction and with any polarization.

The Table Mountain Research project has constructed a prototype antenna (see Figure 2) that uses three orthogonally mounted dipoles to sample the electromagnetic field. From this information it should be possible to compute the total RF field incident on the antenna as well as the polarization of the signal. Preliminary testing of this prototype looks promising. Work continues to characterize the antenna's response, and to develop the instrumentation and signal processing needed.

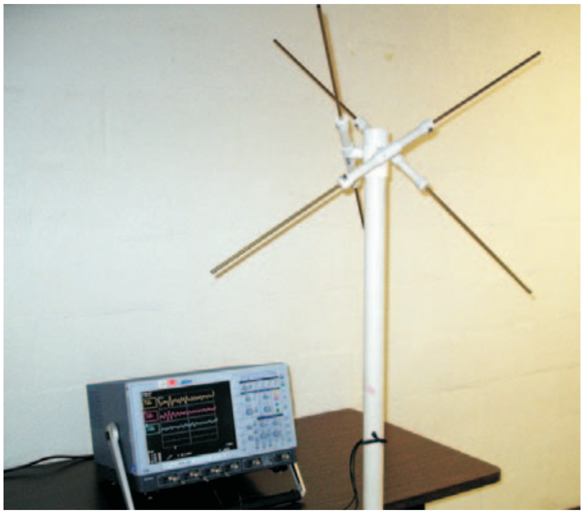

Figure 2. Prototype 3-axis antenna (photo by F.H. Sanders).

Radar Testing

This year the Table Mountain Field Site was used to provide critical support to the administrations of the United States and Japan through collaborative work in association with the ITU-R Joint Rapporteur Group (JRG) 1A-1C-8B and Working Party 8B (WP-8B). Data were gathered on emission spectra, antenna patterns, and pulse waveforms from a variety of S-band (3000 MHz) and X-band (9400 MHz) maritime navigation and surface search radars. The Table Mountain facility provided an ideal location for such measurements, combining the features of open, flat terrain; a radio-quiet environment; support facilities for measurement equipment and crews; and easy access from the Boulder laboratory. Five maritime radars shipped from Japan were measured at Table Mountain over a period of two weeks (see photos, pp. 57 and 70). The emission data were subsequently used by both governments to support their activities in the JRG and WP-8B. It is anticipated that similar measurements will be performed on other radar transmitters at Table Mountain in the future.

Cooperative Research and Development Projects at Table Mountain

- FirstRF Corporation
- RF Metrics Corporation
- Savi Technologies, Inc.
- Spectrum Mapping, LLC
- University of Colorado: Ad Hoc UAV and Ground Networking (AUGNET) research group

Recent Publication

J.W. Allen, "Gain characterization of the RF measurement Path," NTIA Report TR-04-410, Feb. 2004.

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Spectrum Efficiency Research

Outputs

- Report on Federal LMR systems in the Washington, DC, area.
- White paper on spectrum efficiency concepts.
- Consultation with OSM on spectrum efficiency planning.

NTIA is deeply committed to an extensive multi-pronged program to improve the spectrum efficiency of Federal radio systems. This program was given additional importance by the May 2003 announcement of a November 30 Presidential Spectrum Policy Initiative to promote the development and implementation of a U.S. spectrum management policy for the 21st century. More recently, the NTIA administrator, Michael Gallagher, announced a multi-year effort to carry out a series of spectrum efficiency directives contained in a November 2004 Presidential Memorandum to multiple Federal departments. Although most of this work will be accomplished by NTIA's Office of Spectrum Management (OSM) in Washington, ITS is also playing a key role in several aspects of this work.

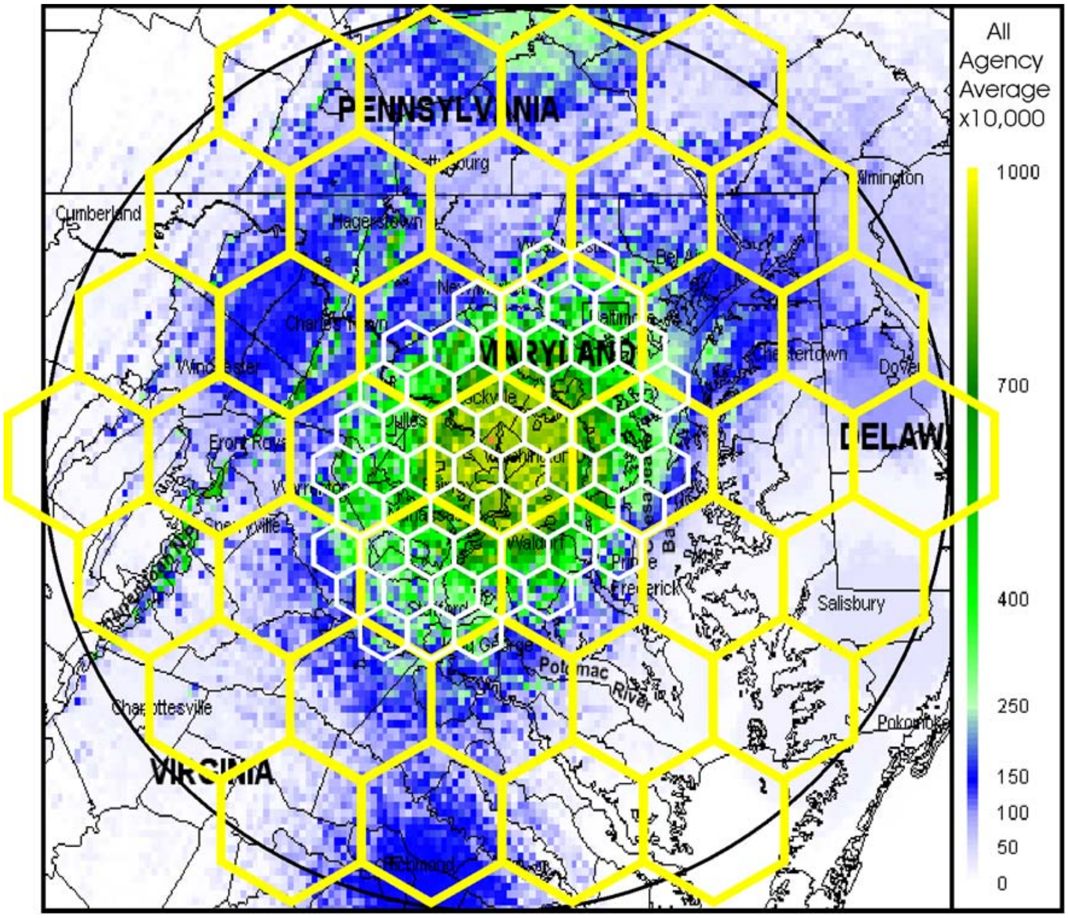
ITS is working with OSM to develop theoretical concepts and practical applications of improved spectrum efficiency. A problem is that "spectrum efficiency" can mean many things — some of them contradictory — and ITS has been active in helping to sort out concepts that will be useful in guiding Federal policies toward more effective use of the radio spectrum. During FY 2004, ITS prepared an initial paper on Spectrum Efficiency Concepts to guide discussion on some of the problematic aspects of spectrum efficiency that needed to be resolved to help NTIA develop improved policies and practices.

In related work, ITS is currently examining possible metrics (i.e., equations) that describe the spectrum efficiency of several types of radio services. This work will serve partly as a "reality check" to show whether it is practical to routinely and rigorously compute the spectrum efficiency of existing or proposed Federal radio systems.

ITS has been assisting in a modeling effort to see whether the current myriad of single-agency Federal mobile radio systems in the Washington, DC, area could be efficiently replaced by one large shared trunked radio system. The first part of this work was completed last year, including an NTIA Report (see Recent Publications below). This work investigated the current Federal land mobile radio (LMR) systems in the vicinity of Washington, DC. A major part of this study was to develop a signal capacity (SC) model that counted the number of independent radio signals available to a mobile user on a geographical basis, using the Government Master File (GMF) of Federal radio licenses as a source of detailed data. The SC model was developed to provide a combined geographical coverage "footprint" of the multiple independent existing radio systems now serving Federal Agencies. The SC model showed that as many as 268 separate LMR radio channels were available to a mobile user in the downtown Washington area in the 162-174 MHz band, as well as summarizing the current geographical coverage that a future shared trunked system would need to duplicate.

The other major input to a model for the design of future LMR systems was the measurement of actual LMR traffic (Erlangs) in the Washington area, using the ITS Radio Spectrum Measurement System (RSMS). These measurements were completed in November 2004, and the results will be used to describe the total amount of traffic that a future shared radio system should be designed to handle.

The design of future alternative shared LMR systems will be based on the SC geographical coverage data and the RSMS measured traffic data. The figure shows the average signal capacity (ASC) map for Washington, DC, overlaid with a 100-mi radius circle. The ASC map shows the number of independent radio systems per square mile (actual ACS values are multiplied by 10,000 on the map). This ASC data will be used to design several generic types of trunked radio systems, whose 20-mi radius coverage areas are shown as the large yellow hexagons. Two other generic trunked systems will use a combination of large-coverage cells in the outlying areas and two sizes of small-coverage cells (smaller white



Average signal capacity map for all Federal agencies within 100 miles of Washington, DC, overlaid with generic mobile radio base station coverage areas.

hexagons) in the central metropolitan areas. These three generic designs will be evaluated using four assumptions about the total number of users participating in the shared system, including traffic levels equivalent to 30%, 100%, 300%, and 1000% of the current RSMS-measured traffic levels. The final report is expected to evaluate each of the three system architectures under the conditions of the four traffic loading assumptions. These studies will provide useful insights for how the advantages of large shared trunked systems would be expected to scale for a range of alternative system architectures and operational scenarios.

Recent Publications & Presentations

G. Patrick, et al., "Spectrum effectiveness initiative: Phase 1 — Study of Federal operations in the 162-174 MHz band in the Washington, DC area," NTIA Report 04-415, in progress.

G. Patrick, C. Hoffman, and R. Matheson, "Signal capacity modeling for shared radio system planning," in "Proceedings of the International Symposium on Advanced Radio Technologies: March 2-4, 2004," J.W. Allen, T.X Brown, D.C. Sicker, and J. Ratzloff (Eds.), NTIA Special Publication SP-04-409, Mar. 2004, pp 77-86.

R. Matheson, "Alternative spectrum management techniques," tutorial presented at the International Symposium on Advanced Radio Technologies, Mar. 2004.

R. Matheson, "Spectrum measurements," invited presentation at the National Academy of Sciences, Committee on Wireless Technology Prospects and Policy Options, San Diego, Jul. 22, 2004.

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Investigation into Interference Potential of Ultrawideband Signals

Outputs

- Methods developed and measurements performed to determine UWB interference susceptibility of C-band satellite digital television receivers.
- Measurements performed to determine the effects of gating on the interference potential of Gaussian noise.
- Comparative measurements and analysis of DS-UWB and MB-OFDM signals.
- IEEE 802.15.3a standards contribution.

On March 22, 2004, ITS entered into a cooperative research and development agreement with Motorola/Freescale Inc. A primary goal of this research is to identify characteristics of various ultrawideband (UWB) waveforms that correlate with performance degradation of legacy victim receivers.

UWB interference provides a unique challenge for spectrum policy makers. Narrow pulses, inherent to "conventional" UWB signals, spread power across a frequency band that can simultaneously cover operational bands for a number of victim receivers. UWB proponents have argued that UWB power spectral density is below the noise threshold of narrowband receivers and therefore causes little interference. UWB opponents argue that proliferation of UWB consumer devices will create a significantly degraded radio environment due to increased power spectral density of aggregate UWB interference and increased probability of encountering UWB devices.

In 2002, the Federal Communications Commission permitted low-power UWB emissions between 3.1 GHz and 10.6 GHz. The rules require that UWB signals have a 10-dB bandwidth greater than 500 MHz and greater than 25% of the center frequency without specifying how that bandwidth is achieved (i.e., which modulation is used). Consequently, these regulations expanded the scope of UWB to include modulations with defined carriers and band-limited pulses in addition to "conventional" carrier-less UWB signals.

An example of the increased scope of UWB is the development of the multi-band orthogonal frequency-division multiplexing (MB-OFDM) technology for short range, high data rate wireless communications. MB-OFDM achieves the ultra-wide bandwidth criteria with a 528-MHz wide OFDM signal that hops between 14 different bands. Direct-sequence ultrawideband (DS-UWB) is another technology recently developed for short-range wireless communications that combines conventional spread spectrum techniques and pulse shaping. Figures 1 and 2 illustrate amplitude statistics of simulated DS-UWB and MB-OFDM signals in various limiting bandwidths.

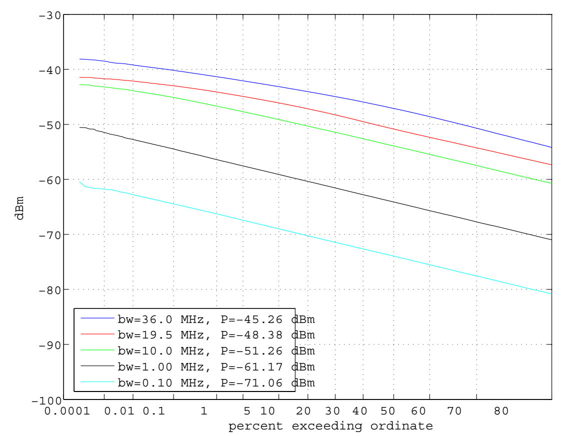

Figure 1. Amplitude statistics of DS-UWB (code = 0, -1, -1, -1, 1, 1, 1, -1, 1, 1, -1, 1).

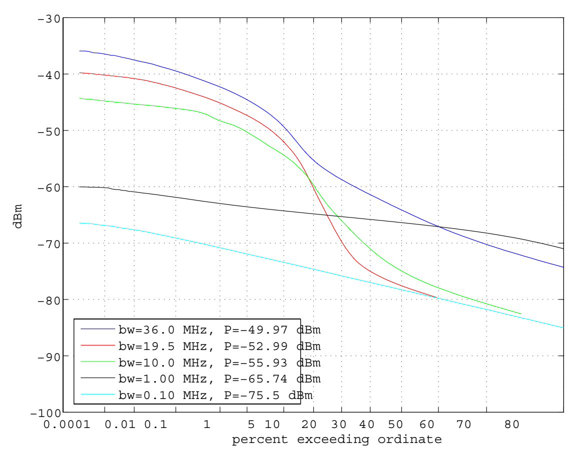

Figure 2. Amplitude statistics of MB-OFDM that hops between three bands and dwells at each band for a single MB-OFDM word (312.5 nanoseconds).

Figure 3. Test set-up (photograph by F.H. Sanders).

Proponents of DS-UWB and MB-OFDM both seek standardization from IEEE 802.15 working group 3a on high-rate (greater than 20 million bits per second) wireless personal area networks (WPAN). As the name implies, WPAN is intended for short-distance (<10 meters) wireless networking of portable and mobile computing devices, e.g., PCs, personal digital assistants, digital cameras, mobile phones, and other consumer electronics. The standards process has reached a stalemate. At the heart of the issue lie fundamental questions regarding the interference UWB devices impose on legacy victim receivers.

This study was intended to address UWB interference issues and provide scientific answers to the following questions: (1) Which type of modulation, DS-UWB or MB-OFDM, causes the most performance degradation to victim receivers? (2) Do existing FCC compliance metrics and measurement procedures adequately predict performance degradation due to UWB interference? To get at these questions ITS focused on a single victim receiver, C-band satellite digital television.

C-band satellite television receivers provide an excellent victim receiver to be tested for UWB interference susceptibility because: (1) the operational frequency band (3.7–4.2 GHz) lies within the band allocated for UWB emissions; (2) signals transmitted by satellites are weak at Earth stations, making them vulnerable to interference; and (3) satellite television broadcast technologies cover a broad range of communications techniques (analog and digital) and signal processing concepts (modulation, multiplexing, error correction, interleaving, encryption) allowing for a number of operational scenarios to be investigated.

In this study, ITS attempted to identify measurable interference metrics that correlate with performance degradation in C-band satellite receivers. Toward this end, we developed procedures for characterization of signals representative of existing and proposed UWB systems. Additionally, we designed a conducted experiment comprised of a satellite signal simulator, interference generation by a Vector Signal Generator, and performance monitoring of the victim receiver via an MPEG transport stream monitor.

Additional information may be found at: www.its.bldrdoc.gov/home/programs/uwb_interference/.

Recent Contribution

IEEE 802.15.3a standards contribution, "Estimating and Graphing the Amplitude Probability Distribution Function of Complex-Baseband Signals," by R. Achatz, M. Cotton, and R. Dalke.

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NOAA Weather Radio Performance Study

Outputs

- VHF receiver and transmitter measurements and testing.
- FSK simulation.
- Baseband waveform analysis.

The National Weather Service (NWS) tasked ITS to examine the NOAA Weather Radio (NWR) system from signal generation to signal reception. NWR broadcasts round-the-clock weather information to all U.S. states, coastal waters, and protectorates. The NWR network consists of over 900 FM transmitters operating at 100, 300, and 1000 watts. Each transmitter uses one of seven evenly-spaced frequencies between 162.400 and 162.550 MHz, with a bandwidth of 25 kHz. In addition to the familiar audio weather forecasts, NWR can provide a digital alert signal consisting of a two-tone frequency shift key (FSK) 521 symbol-per-second waveform. The symbols follow the NWR Specific Area Message Encoding (SAME) protocol system. An alert uses one of over 75 SAME event codes and numerous location codes to warn the public of natural and man-made hazards. There are four levels of alerts in increasing significance: statements, emergencies, watches, and warnings. Messages range from a High Wind Warning to more recently added events such as a 911 telephone outage emergency. As part of its mandate to be an all-hazards network, NWR also has been chosen to carry public notices of terrorist attacks and changes in the color-coded national threat level.

ITS conducted a series of receiver measurements that were based on tests outlined in the recent Consumer Electronics Association standard entitled "Receiver Performance Specification for Public Alert Receivers" (CEA-2009) which describes the proposed performance requirements of NWR receivers. These receivers are not only capable of decoding weather related SAME messages, but are also able to decode messages associated with the new mandate to make NWR an all-hazards public alert network. ITS performed CEA-2009 tests on a wide range of NWR receivers to ascertain their performance. Additionally, ITS devised a number of measurements not in the specification. This work will be used to determine baseline operational parameters (e.g., sensitivity and out-of-band rejection) for off-the-shelf NWR receivers and future NWR receivers as they are brought to the market. This information will aid the NWS in maintaining and developing enhancements to the NWR network.

A series of tools were developed during the course of this project, including software to simulate SAME waveforms, Audio FSK (AFSK) modulator and demodulation routines, and other tools to create waveforms to stress NWR receivers. Figure 1 shows output from one of the performance tests that made use of the ITS-developed SAME simulation tools. In this experiment, simulated NWR transmissions were made at frequencies at and near 162.425 MHz in order to determine the receiver's reception bandwidth.

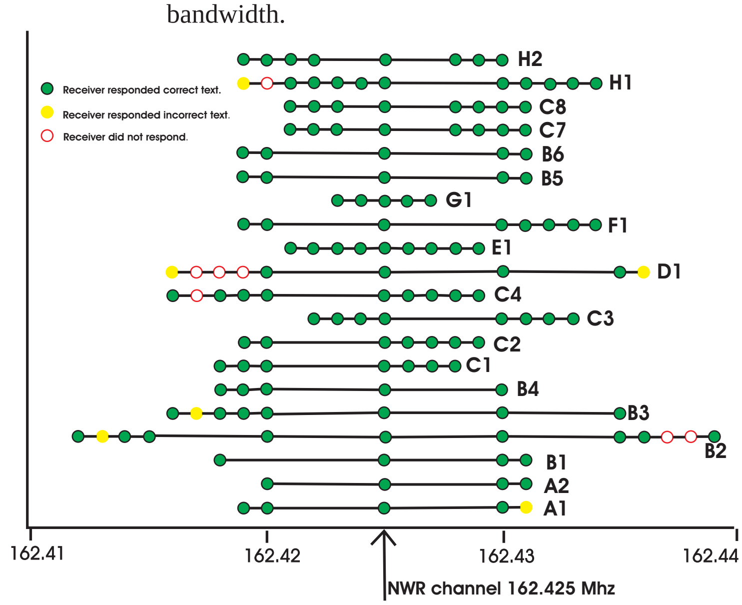

Figure 1. Output from receiver performance test. A black-bordered green circle indicates that the receiver responded at that frequency with text matching the event broadcast. A full yellow circle means the receiver responded with text other than that for the event broadcast. A red-edged empty circle means the receiver did not respond at that frequency.

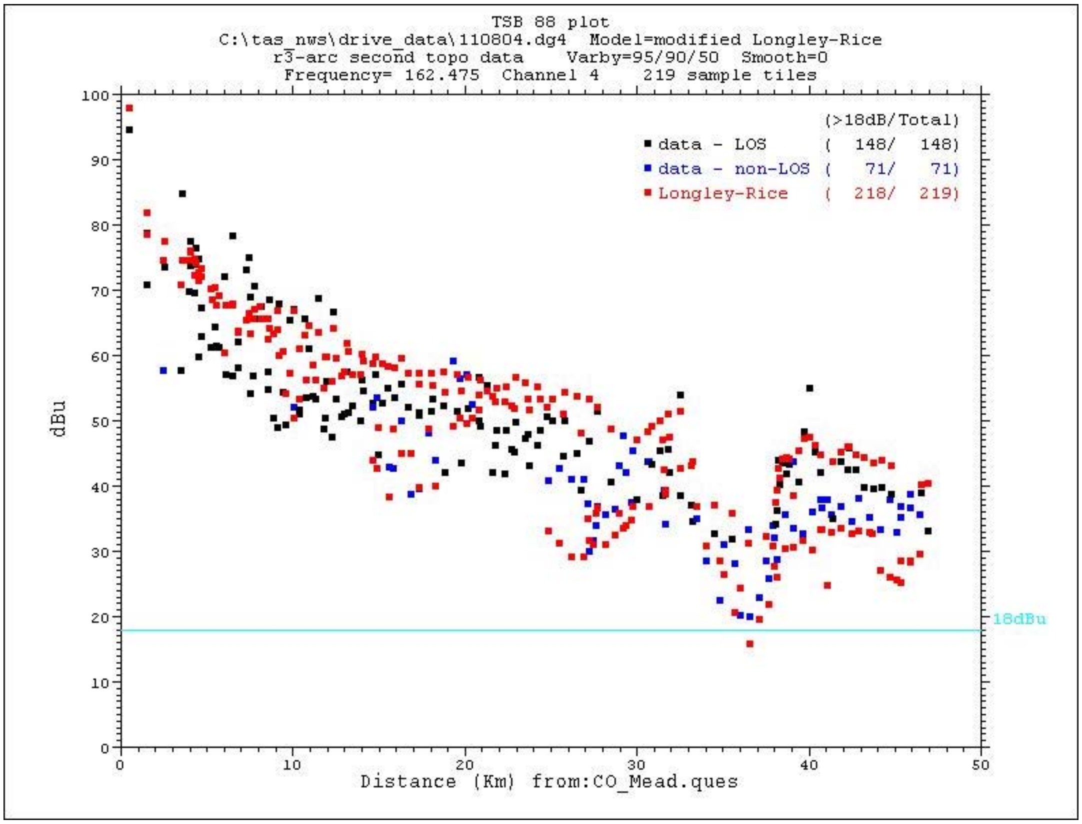

Figure 2. Scatter diagram output from drive test. The model-generated field strength estimate for each tile appears as a red dot. The black and blue dots are data points. These data points are different colors to differentiate between line of sight (LOS) locations and non-LOS, as determined by the terrain profile.

The study also identified measurement techniques that can be used to maintain and evaluate NWR transmitters at a high performance level. The general recommendations outlined in the study allow the NWS to conduct coverage and signal quality tests. The ITS transmitter measurement system was mounted in an automobile and driven through the area of interest. One of the most interesting outputs from the data collection and analysis software developed from this project can be seen in Figure 2. The scatter diagram is used to determine if the coverage criteria for a NWR transmitter has been satisfactorily met. Each dot represents a 1 km^2 tile in the coverage area. For each tile the drive test passed through, there may have been several subsamples taken. Each subsample was collected in such a way as to mitigate the effects of Rayleigh fading. Each subsampled tile was then compared to the ITS propagation model output from ITS's Telecommunications Analysis (TA) Services (pp. 36-37) and against prescribed performance criteria. In this case that minimum performance dictates that the field strength must be greater than 18 dBµV.

In the course of this work, interoperability of the baseband SAME encoders was examined in some detail. These are the devices that generate SAME messages at the command of local NWS offices. These devices are divided into two classes; those governed by NWS specification and those under FCC control as part of the Emergency Alert System (EAS). An effort was made to characterize these devices by examining such parameters as frequency stability, symbol time statistics and interface performance.

This is only a small sampling of the performance measurements and outputs that were conducted to evaluate the NWR system. ITS plays a pivotal role in evaluating the NWR network and other communications systems that are vital to the general public.

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